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(54) **MULTI-QUANTUM WELL STRUCTURE AND LED DEVICE INCLUDING THE SAME**

(71) Applicant: **XIAMEN SAN'AN OPTOELECTRONICS CO., LTD.**, Xiamen (CN)

(72) Inventors: **Han Jiang**, Wuhu (CN); **Yung-Ling Lan**, Wuhu (CN); **Wen-Pin Huang**, Wuhu (CN); **Changwei Song**, Wuhu (CN); **Li-Cheng Huang**, Wuhu (CN); **Feilin Xun**, Xiamen (CN); **Chan-Chan Ling**, Wuhu (CN); **Chi-Ming Tsai**, Wuhu (CN); **Chia-Hung Chang**, Wuhu (CN)

(73) Assignee: **Xiamen San'An Optoelectronics Co., Ltd.**, Fujian (CN)

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Apr. 18, 2017 (CN) 201710252090.7

(51) **Int. Cl.**

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H01L 33/06	(2010.01)

(Continued)

(52) **U.S. Cl.**
CPC ***H01L 33/06*** (2013.01); ***H01L 33/0075*** (2013.01); ***H01L 33/22*** (2013.01); ***H01L 33/32*** (2013.01)

(58) **Field of Classification Search**
CPC H01L 33/22; H01L 33/06; H01L 33/32; H01L 33/0075; H01L 33/12
See application file for complete search history.

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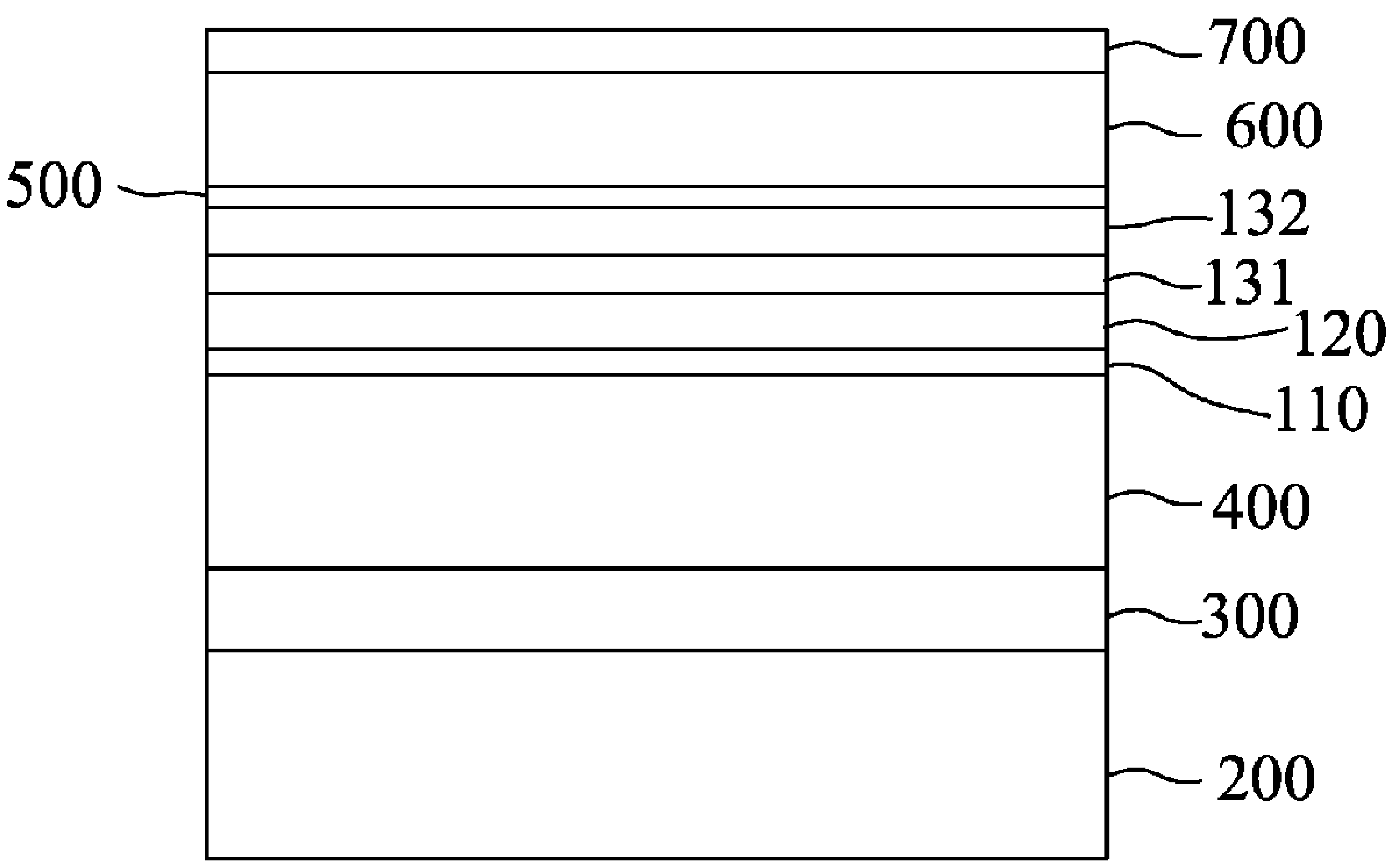
Primary Examiner — Savitri Mulpuri
(74) *Attorney, Agent, or Firm* — Rosenberg, Klein & Lee

(57) **ABSTRACT**

Disclosed is a multi-quantum well structure including a stress relief layer, an electron-collecting layer disposed on the stress relief layer, and an active layer including a first active layer unit that is disposed on the electron-collecting layer. The first active layer unit includes potential barrier sub-layers and potential well sub-layers being alternately stacked, in which at least one of the potential barrier sub-layers has a $GaN/Al_{x1}In_{y1}Ga_{(1-x1-y1)}N/GaN$ stack, where $0<x1\leq 1$ and $0\leq y1<1$, and for the remainder of the potential barrier sub-layers, each of the potential barrier

(Continued)



sub-layers is a GaN layer. An LED device including the multi-quantum well structure is also disclosed.

20 Claims, 3 Drawing Sheets

(51) **Int. Cl.**

H01L 33/22	(2010.01)
H01L 33/32	(2010.01)

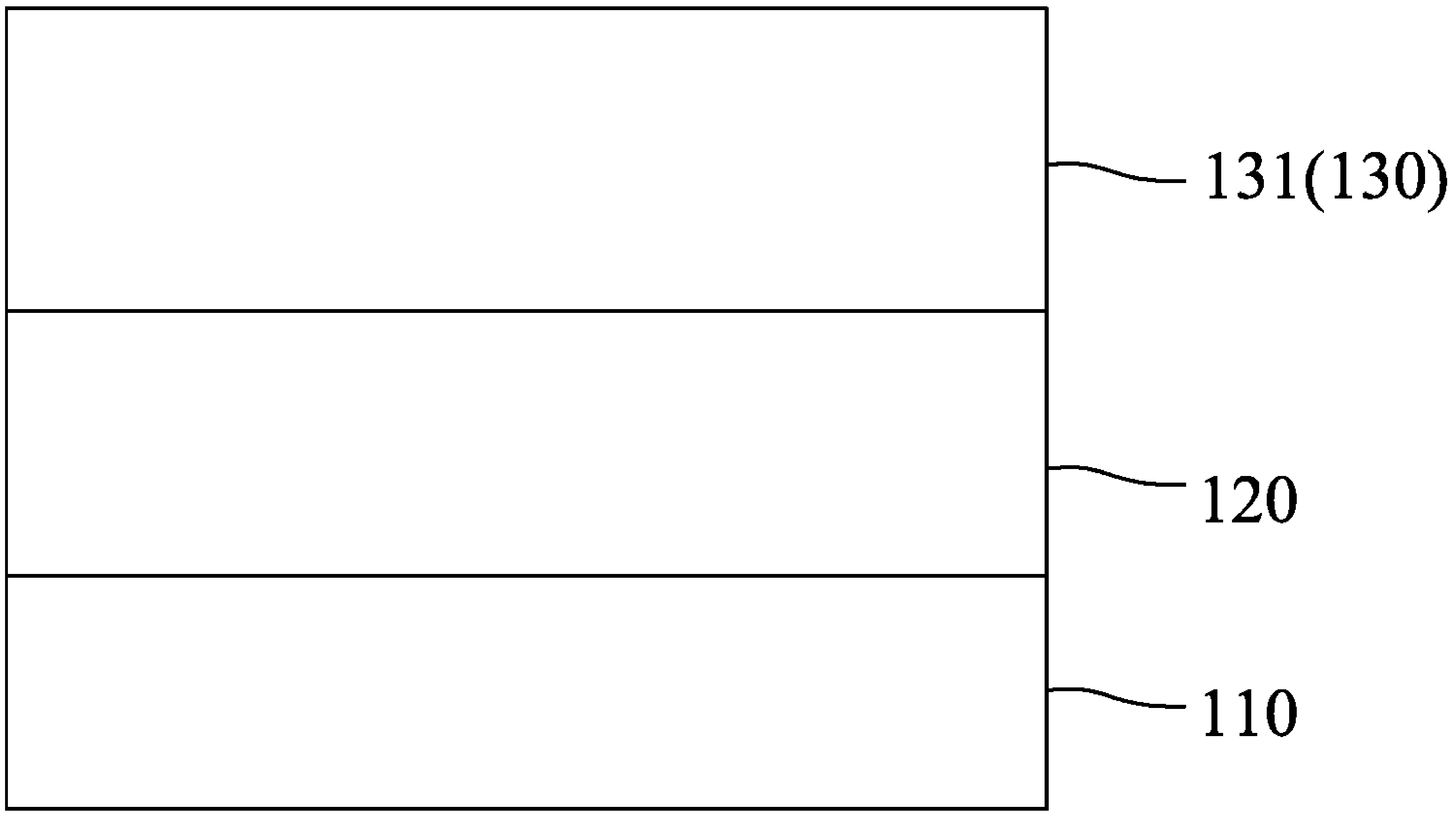


FIG.1

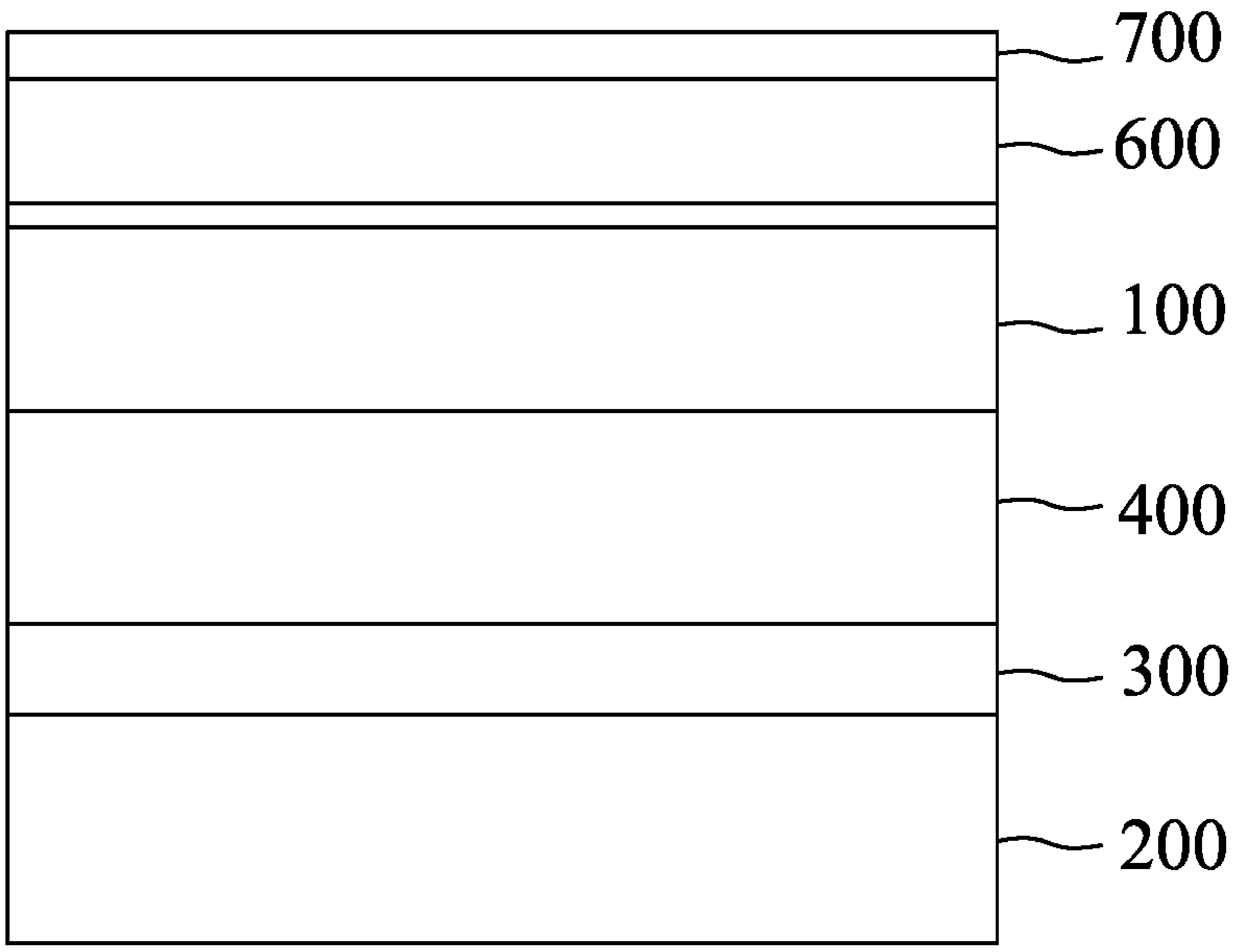


FIG.2

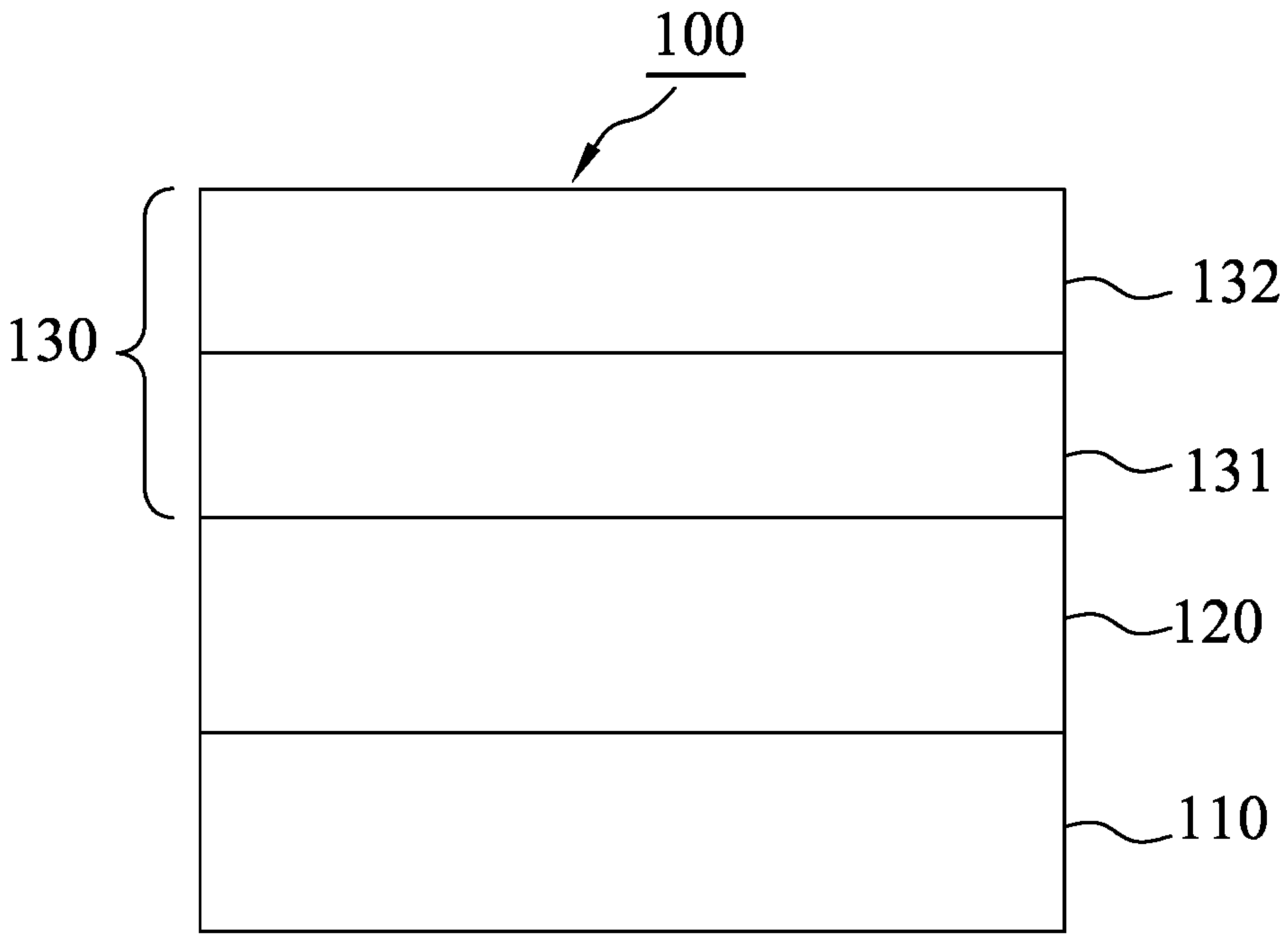


FIG.3

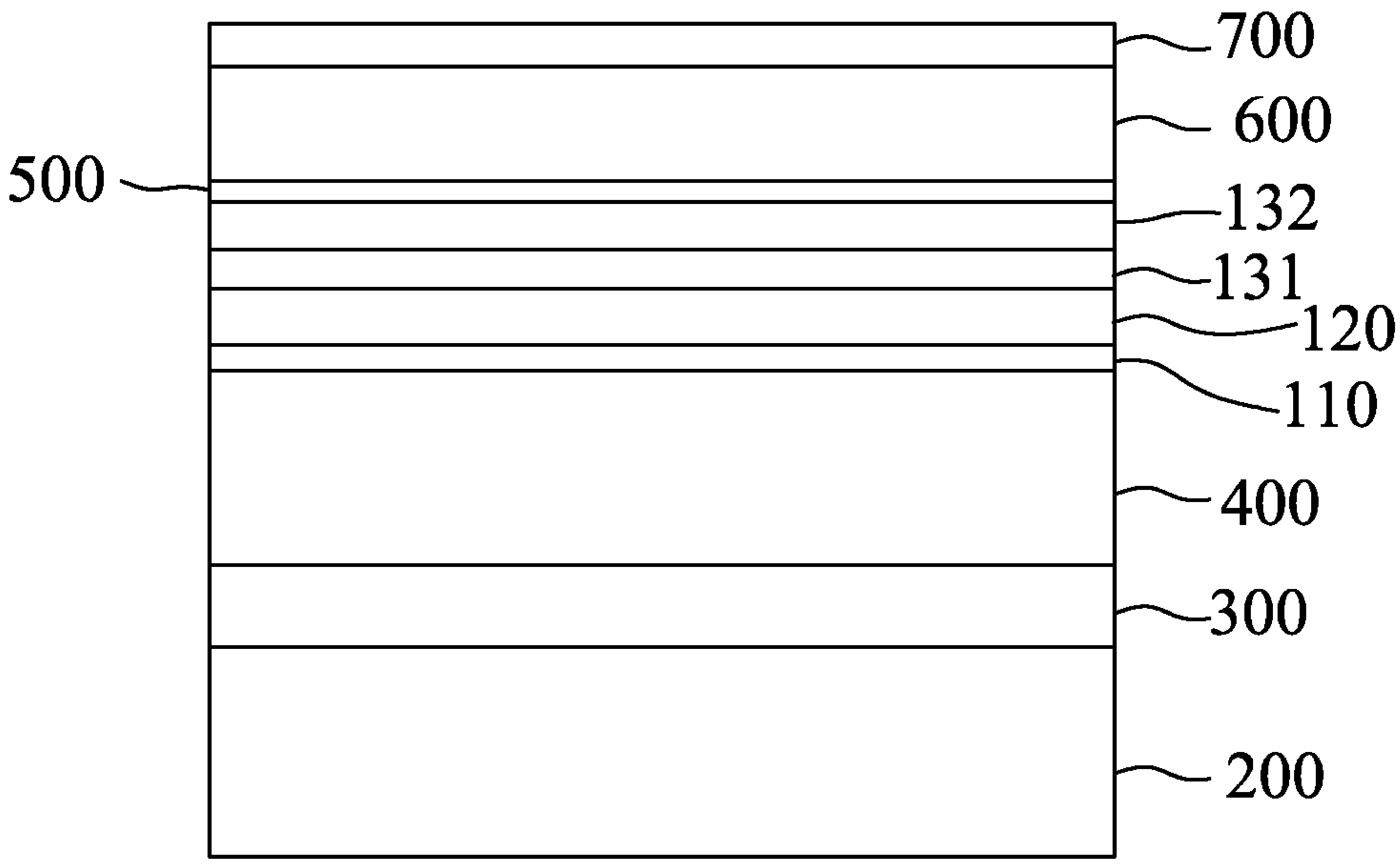


FIG.4

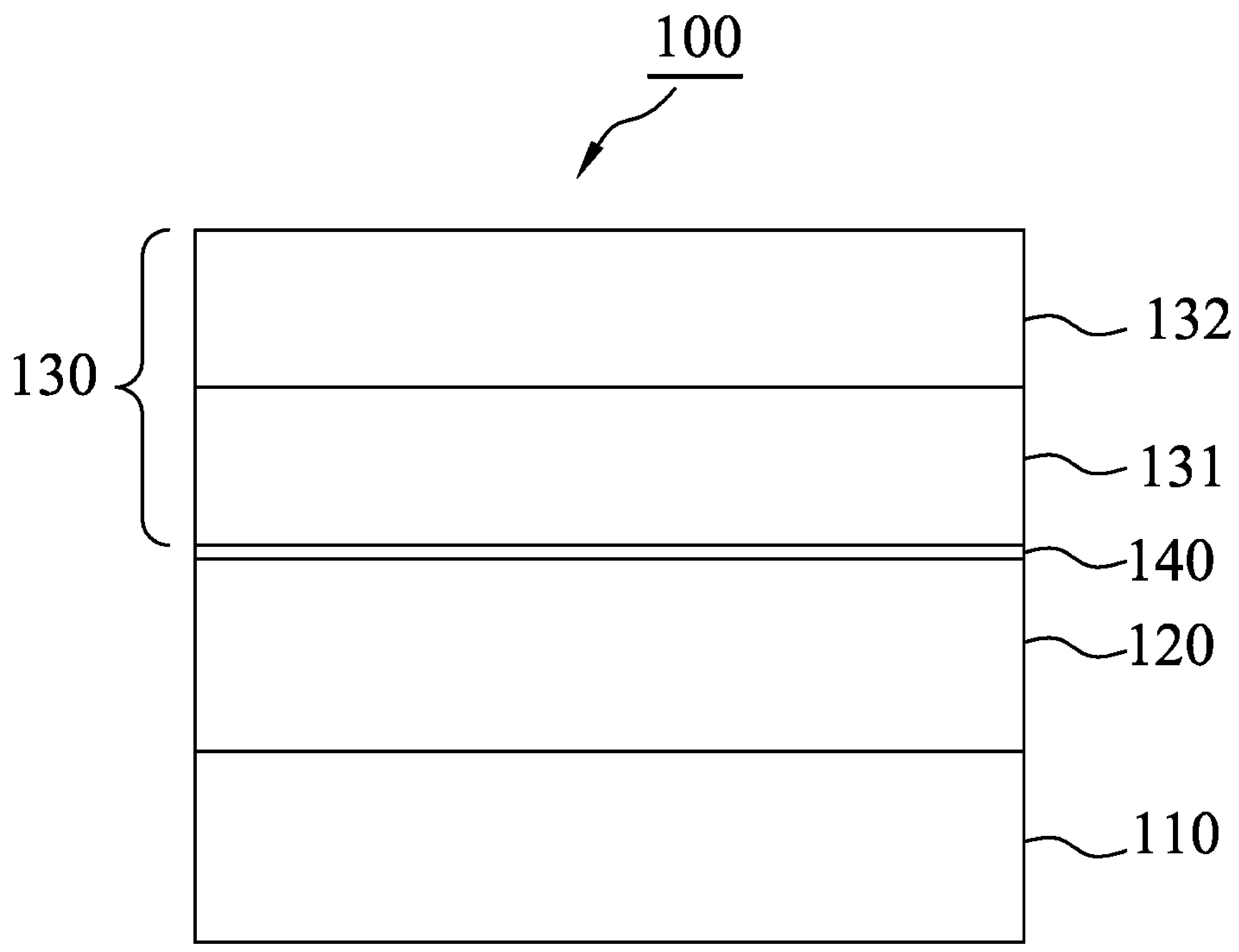

100
130
132
131
140
120
110

FIG.5

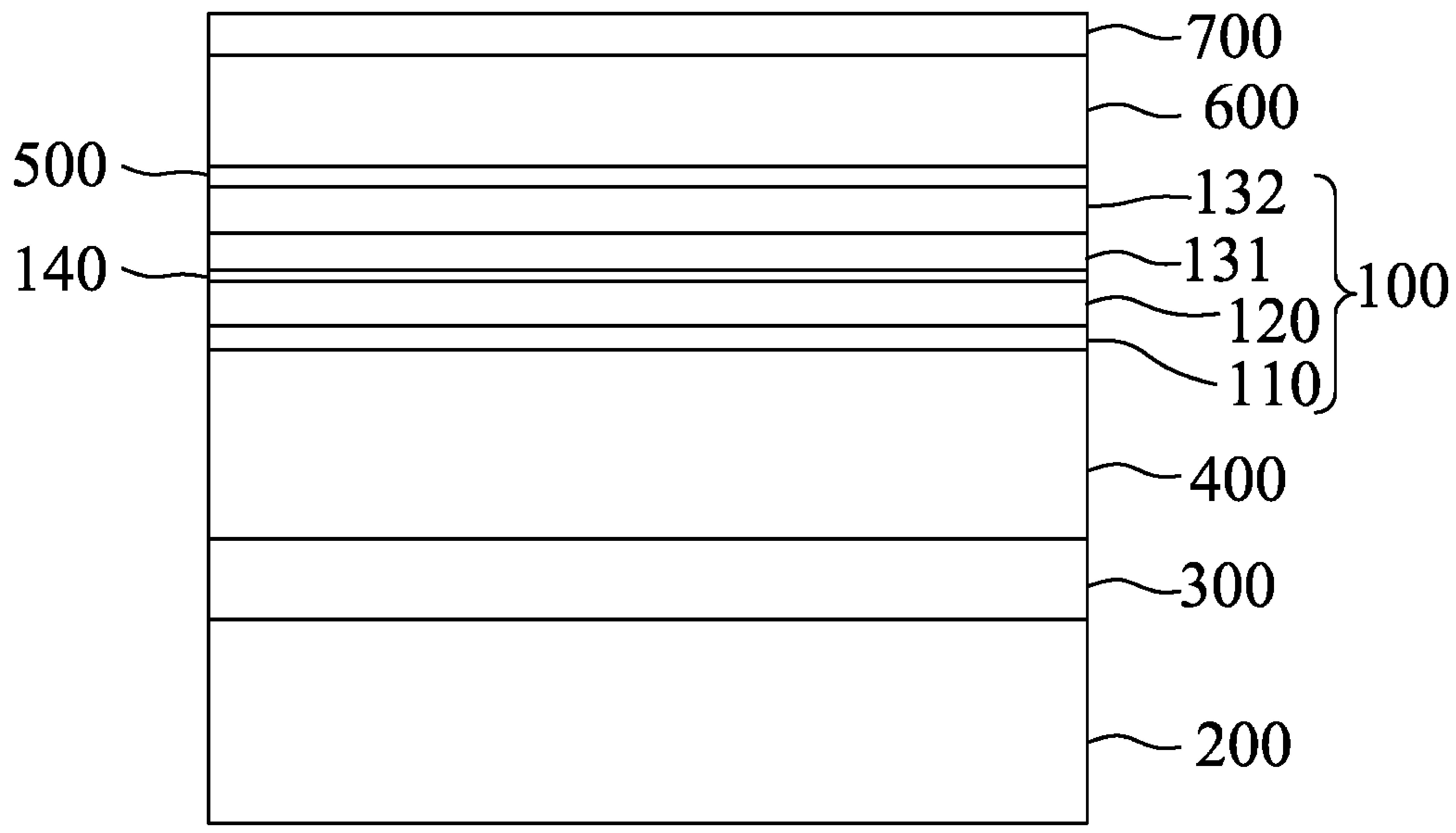

700
600
500
132
131
140
120
110
100
400
300
200

FIG.6

MULTI-QUANTUM WELL STRUCTURE AND LED DEVICE INCLUDING THE SAME

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part (CIP) of International Application No. PCT/CN2018/078655, entitled "MULTI-QUANTUM WELL STRUCTURE AND LIGHT-EMITTING DIODE THEREOF," filed on Mar. 12, 2018, which claims priority of Chinese Invention Patent Application No. 201710252090.7, filed on Apr. 18, 2017.

FIELD

This disclosure relates to a multi-quantum well structure, and an LED device including the multi-quantum well structure.

BACKGROUND

As the light-emitting diode (LED) industry gradually develops, an increasing need for developing white LED devices with high luminance and a tolerance toward high current density is observed. Meanwhile, miniaturization of the LED devices under the premise of maintaining their properties (especially luminance) is highly desirable in order to increase the market competitiveness of the LED devices. This trend further elevates the need for tolerance toward high current density in an epitaxial structure of the LED devices, with the efficiency droop effect remaining as one of the biggest problems to be solved.

Conventional epitaxial designs for increasing the tolerance toward high current density and for reducing the efficiency droop effect in an LED device are usually implemented by modifying the structure and composition of an electron-blocking layer disposed on an active layer. Such conventional epitaxial designs may include, for example, gradually changing an Al content in an AlGaN electron-blocking layer, or forming the electron-blocking layer with a superlattice structure such as an AlGaN/GaN superlattice structure, an AlN/GaN superlattice structure, and an AlN/AlGaN superlattice structure. However, such epitaxial designs may not alleviate the energy-band distortion in the active layer of the LED device. Further, a modification in structure and composition may increase the thickness of the electron-blocking layer, which results in a loss of light-emitting efficiency. In addition, a thick electron-blocking layer with a relatively high Al composition may further enlarge openings of V-pit defects in the LED device, which results in a thicker P-type cladding layer being needed to fill and flatten an epitaxial layer of the LED device in order to prevent electrostatic discharge and a loss of infrared functionalities.

SUMMARY

Therefore, a first object of the disclosure is to provide a multi-quantum well structure that can alleviate or eliminate at least one of the drawbacks of the prior art. A second object of the disclosure is to provide a light-emitting diode (LED) device including the multi-quantum well structure.

According to a first aspect of the disclosure, a multi-quantum well structure includes a stress relief layer, an electron-collecting layer disposed on the stress relief layer, and an active layer including a first active layer unit that is disposed on the electron-collecting layer. The first active layer unit includes a plurality of potential barrier sub-layers and a plurality of potential well sub-layers being alternately stacked. At least one of the potential barrier sub-layers of the first active layer unit has a GaN/$Al_{x1}In_{y1}Ga_{(1-x1-y1)}N$/GaN stack, where $0<x1\leq1$ and $0\leq y1<1$, and for the remainder of the potential barrier sub-layers of the first active layer unit, each of the potential barrier sub-layers is a GaN layer.

According to a second aspect of the disclosure, an LED device includes a substrate, a buffer layer disposed on the substrate, an N-type cladding layer disposed on the buffer layer, the multi-quantum well structure of the first aspect of the disclosure which is disposed on the N-type cladding layer, a P-type cladding layer disposed on the multi-quantum well structure, and a P-type contact layer disposed on the P-type cladding layer.

BRIEF DESCRIPTION OF THE DRAWINGS

Other features and advantages of the disclosure will become apparent in the following detailed description of the embodiments with reference to the accompanying drawings, in which:

FIG. **1** is a schematic view of a first embodiment of a multi-quantum well structure according to the disclosure;

FIG. **2** is a schematic view of a first embodiment of a light-emitting diode (LED) device according to the disclosure;

FIG. **3** is a schematic view of a second embodiment of the multi-quantum well structure according to the disclosure;

FIG. **4** is a schematic view of a second embodiment of the LED device according to the disclosure;

FIG. **5** is a schematic view of a third embodiment of the multi-quantum well structure according to the disclosure; and

FIG. **6** is a schematic view of a third embodiment of the LED device according to the disclosure.

DETAILED DESCRIPTION

Hereinafter, the embodiments will be described in detail with reference to the accompanying drawings. It should be noted that the drawings, which are for illustrative purposes only, are not drawn to scale, and are not intended to represent the actual sizes or actual relative sizes of the components of the multi-quantum well structure and the LED device including the same. Moreover, where considered appropriate, reference numerals have been repeated among the figures to indicate corresponding or analogous elements, which may optionally have similar characteristics.

First Embodiment

Referring to FIG. **1**, a first embodiment of a multi-quantum well structure **100** according to the disclosure includes a stress relief layer **110**, an electron-collecting layer **120** disposed on the stress relief layer **110**, and an active layer **130**. The active layer **130** includes a first active layer unit **131** that is disposed on the electron-collecting layer **120**. The first active layer unit **131** of the active layer **130** includes multiple pairs of sub-layers, the sub-layers in each pair including a potential barrier sub-layer and a potential well sub-layer. The plurality of potential barrier sub-layers and the plurality of potential well sub-layers of the first active layer unit **131** are alternately stacked. At least one of the potential barrier sub-layers of the first active layer unit **131** has a GaN/$Al_{x1}In_{y1}Ga_{(1-x1-y1)}N$/GaN stack, where $0<x1\leq1$ and $0\leq y1<1$, and for the remainder of the potential barrier sub-layers of the first active layer unit **131**, each of the potential barrier sub-layers is a GaN layer. In this embodiment, each of the potential well sub-layers of the first active layer unit **131** is an InGaN layer.

In certain embodiments, in the GaN/$Al_{x1}In_{y1}Ga_{(1-x1-y1)}N$/GaN stack, y1=0 and 0.05≤x1≤1. That is, said at least one of the potential barrier sub-layers of the first active layer unit **131** has the GaN/$Al_{x1}Ga_{(1-x1)}N$/GaN stack. In the GaN/$Al_{x1}Ga_{(1-x1)}N$/GaN stack (i.e., y1=0), the range of x1 may be 0.1≤x1≤1, 0.05≤x1≤0.20, or 0.1≤x1≤0.15.

In certain embodiments, the one of the potential barrier sub-layers having the GaN/$Al_{x1}In_{y1}Ga_{(1-x1-y1)}N$/GaN stack in the first active layer unit **131** is disposed farthest away from the electron-collecting layer **120**. In certain embodiments, in the first active layer unit **131**, the one of the potential barrier sub-layers farthest away from the electron-collecting layer **120** is undoped, and for the remainder of the potential barrier sub-layers, each of the potential barrier sub-layers is one of an n-doped layer and a p-doped layer.

In certain embodiments, the one of the potential barrier sub-layers of the first active layer unit **131** farthest away from the electron-collecting layer **120** has a thickness ranging from 140 Å to 190 Å, and has the GaN/$Al_{x1}Ga_{(1-x1)}N$/GaN stack (i.e., y=0) with 0.05≤x1≤1. A thickness of $Al_{x1}Ga_{(1-x1)}N$ in the GaN/$Al_{x1}Ga_{(1-x1)}N$/GaN stack ranges from 20 Å to 30 Å.

In certain embodiments, the stress relief layer **110** includes less than 30 pairs of sub-layers, the sub-layers in each pair including a potential barrier sub-layer and a potential well sub-layer. The plurality of potential barrier sub-layers and the plurality of potential well sub-layers of the stress relief layer **110** are alternately stacked. Each of the potential barrier sub-layers is a GaN layer, and each of the potential well sub-layers is an InGaN layer. An In amount in the stress relief layer **110** is less than 15% based on a total weight of the stress relief layer **110**.

In certain embodiments, the stress relief layer **110** is an InGaN layer, where the In amount in the stress relief layer **110** is less than 15% based on a total weight of the stress relief layer **110**.

The electron-collecting layer **120** includes multiple pairs of sub-layers, the sub-layers in each pair including a potential barrier sub-layer and a potential well sub-layer. The plurality of potential barrier sub-layers and the plurality of potential well sub-layers of the electron-collecting layer **120** are alternately stacked. In this embodiment, the electron-collecting layer **120** includes three to six pairs of the sub-layers. One of the potential barrier sub-layers of the electron-collecting layer **120** (e.g., the one farthest away from the stress relief layer **110**) has a GaN/$Al_{x2}Ga_{(1-x2)}N$/GaN stack, where 0.05≤x2≤1, and for the remainder of the potential barrier sub-layers of the electron-collecting layer **120**, each of the potential barrier sub-layers is a GaN layer. In this embodiment, each of the potential well sub-layers of the electron-collecting layer **120** is an InGaN layer having an In concentration lower than that of the potential well sub-layers of the first active layer unit **131**. With the potential barrier sub-layer having the GaN/$Al_{x2}Ga_{(1-x2)}N$/GaN stack, the electron mobility is reduced, and electron leakage under a high current density can be alleviated. In addition, the electron-collecting layer **120** having fewer pairs of the sub-layers would have better lattice quality compared to the conventional electron-collecting layer with greater number of the pairs of the sub-layers.

Referring to FIG. **2**, a first embodiment of a light-emitting diode (LED) device according to the disclosure includes a substrate **200**, a buffer layer **300** disposed on the substrate **200**, an N-type cladding layer **400** disposed on the buffer layer **300**, the aforesaid multi-quantum well structure **100** disposed on the N-type cladding layer **400**, a P-type cladding layer **600** disposed on the multi-quantum well structure **100**, and a P-type contact layer **700** disposed on the P-type cladding layer **600**.

The LED device also includes an electron-blocking layer **500** disposed between the multi-quantum well structure **100** and the P-type cladding layer **600**. The electron-blocking layer **500** has a $Al_{x3}In_{y3}Ga_{(1-x3-y3)}N$ layer or a $Al_{x3}In_{y3}Ga_{(1-x3-y3)}/Al_{x4}In_{y4}Ga_{(1-x4-y4)}N$ superlattice structure, where 0≤x3≤1, 0≤y3≤1, 0≤x4≤1, 0≤y4≤1, x3 and x4 cannot both be 1 or 0, y3 and y4 cannot both be 1 or 0, x3 and y3 cannot both be 0, and x4 and y4 cannot both be 0. In this embodiment, the electron-blocking layer **500** has a thickness ranging from 200 Å to 300 Å.

In comparison to a conventional multi-quantum well structure having a GaN potential barrier sub-layer, the potential barrier sub-layer(s) of the electron-collecting layer **120** having the GaN/$Al_{x2}Ga_{(1-x2)}N$/GaN stack and the potential barrier sub-layer(s) of the active layer **130** having the GaN/$Al_{x1}In_{y1}Ga_{(1-x1-y1)}N$/GaN stack have higher band gaps. Therefore, the electron-collecting layer **120** and the active layer **130** would cooperate with the electron-blocking layer **500** to scatter and block electrons. In addition, as compared to the conventional electron-blocking layer, the electron-blocking layer **500** of the disclosure has a smaller thickness, e.g., 200 Å to 300 Å, which alleviates the light-blocking effect caused by a greater thickness of the conventional electron-blocking layer and improves the brightness of the LED device.

Further, since the one of the potential barrier sub-layers of the first active layer unit **131** having the GaN/$Al_{x1}In_{y1}Ga_{(1-x1-y1)}N$/GaN stack is disposed farthest away from the electron-collecting layer **120** (i.e., immediately adjacent to the electron-blocking layer **500**), the potential barrier sub-layer having the GaN/$Al_{x1}In_{y1}Ga_{(1-x1-y1)}N$/GaN stack may capture electrons leaking from the multi-quantum well structure **100**. Moreover, the potential barrier sub-layer having the GaN/$Al_{x1}In_{y1}Ga_{(1-x1-y1)}N$/GaN stack may improve the lattice quality at an interface between the stress relief layer **110** and the electron-collecting layer **120** and an interface between the electron-collecting layer **120** and the active layer **130**, and may prevent a dopant of the P-type cladding layer **600** from permeating into the active layer **130** during formation of the P-type cladding layer **600**.

Second Embodiment

Referring to FIG. **3**, a second embodiment of the multi-quantum well structure **100** according to the disclosure is similar to the first embodiment of the multi-quantum well **100** except that the second embodiment of the multi-quantum well structure **100** further includes a second active layer unit **132** that is disposed on the first active layer unit **131**. The second active layer unit **132** includes multiple pairs of sub-layers, the sub-layers in each pair including a potential barrier sub-layer and a potential well sub-layer. The plurality of potential barrier sub-layers and the plurality of potential well sub-layers are alternately stacked. Each of the potential barrier sub-layers of the first active layer unit **131** has a band gap larger than that of each of the potential barrier sub-layers of the second active layer unit **132**. In this embodiment, each of the potential barrier sub-layers of the second active layer unit **132** is a GaN layer.

In certain embodiments, each of the potential barrier sub-layers of the first active layer unit **131** has the GaN/$Al_{x1}In_{y1}Ga_{(1-x1-y1)}N$/GaN stack.

In certain embodiments, the first active layer unit **131** includes 4 to 8 pairs of the sub-layers, while the second active layer unit **132** includes 5 to 10 pairs of the sub-layers.

In certain embodiments, in the GaN/$Al_{x1}In_{y1}Ga_{(1-x1-y1)}N$/GaN stack of the first active layer unit **131**, y1=0 and $0.02 \leq x1 \leq 0.06$.

In certain embodiments, the first active layer unit **131** is disposed between the second active layer unit **132** and the electron-collecting layer **120**.

By forming the first active layer unit **131**, electron leakage problem under a high current density may be reduced, and the rate of radiative recombination between electrons and holes and the internal quantum efficiency can be increased, thereby improving the efficiency droop phenomenon. Moreover, the lattice defect in the InGaN potential well sub-layers of the first active layer unit **131** may also be eliminated.

Referring to FIG. **4**, a second embodiment of the LED device is similar to the first embodiment of the LED device except that the second embodiment of the LED device includes the second embodiment of the multi-quantum well structure **100** according to the disclosure. In the second embodiment of the LED device, the first active layer unit **131** has 4 to 8 pairs of the sub-layers, and the second active layer unit **132** has 5 to 10 pairs of the sub-layers. In addition, the electron-blocking layer **500** in the second embodiment of the LED device has a thickness of 250 Å to 300 Å, and has the $Al_{x3}In_{y3}Ga_{(1-x3-y3)}/Al_{x4}In_{y4}Ga_{(1-x4-y4)}N$ superlattice structure, where $0.05 \leq x3 \leq 0.2$, $0 \leq y3 \leq 0.10$, $0.05 \leq x4 \leq 0.2$ and $0 \leq y4 \leq 0.10$.

Third Embodiment

Referring to FIG. **5**, a third embodiment of the multi-quantum well structure **100** according to the disclosure includes a stress relief layer **110**, an electron-collecting layer **120** disposed on the stress relief layer **110**, an interfacial layer **140** disposed on the electron-collecting layer **120**, and an active layer **130** disposed on the interfacial layer **140** oppositely of the electron-collecting layer **120**. The active layer **130** includes a first active layer unit **131** that is disposed on the interfacial layer **140**, and a second active layer unit **132** that is disposed on the first active layer unit **131** oppositely of the interfacial layer **140**.

The first active layer unit **131** of this embodiment has a structure similar to that of the first active layer unit **131** disclosed in the second embodiment, except that, in this embodiment, a number of the pairs of the sub-layers in the first active layer unit **131** ranges from 3 to 5. It should be noted that each of the potential barrier sub-layers of the first active layer unit **131** may have the GaN/$Al_{x1}In_{y1}Ga_{(1-x1-y1)}N$/GaN stack. In certain embodiments, in the GaN/$Al_{x1}In_{y1}Ga_{(1-x1-y1)}N$/GaN stack of the first active layer unit **131**, y1=0 and $0.02 \leq x1 \leq 0.06$.

The second active layer unit **132** of this embodiment includes multiple pairs of sub-layers, the sub-layers in each pair including a potential barrier sub-layer and a potential well sub-layer. The plurality of potential barrier sub-layers and the plurality of potential well sub-layers are alternately stacked. Each of the potential barrier sub-layers of the first active layer unit **131** has a band gap larger than that of each of the potential barrier sub-layers of the second active layer unit **132**. In this embodiment, one of the potential barrier sub-layers of the second active layer unit **132** (e.g., the one disposed farthest away from the first active layer unit **131**) has a GaN/$Al_{x1}Ga_{(1-x1)}N$/GaN stack ($0.1 \leq x1 \leq 1$), and has a thickness ranging from 80 Å to 120 Å, and a thickness of $Al_{x1}Ga_{(1-x1)}N$ in the GaN/$Al_{x1}Ga_{(1-x1)}N$/GaN stack ranges from 20 Å to 30 Å. For the remainder of the potential barrier sub-layers of the second active layer unit **132**, each of the potential barrier sub-layers is a GaN layer. Each of the potential well sub-layers of the second active layer unit **132** is an InGaN layer. In this embodiment, a number of the pairs of the sub-layers in the second active layer unit **131** ranges from 3 to 5.

The electron-collecting layer **120** in this embodiment has the same structure as the electron-collecting layer **120** disclosed in the first embodiment. The interfacial layer **140** disposed between the electron-collecting layer **120** and the active layer **130** has a band gap smaller than that of each of the potential well sub-layers of the active layer **130**. The interfacial layer **140** may confine movement of the electrons and can reduce electron mobility. In certain embodiments, the interfacial layer **140** is an InN layer. In addition, the interfacial layer **140** may alleviate lattice difference between the active layer **130** and the one of the potential barrier sub-layers of the electron-collecting layer **120** farthest away from the stress relief layer **110**.

Referring to FIG. **6**, a third embodiment of the LED device according to the disclosure is similar to the second embodiment of the LED device except that the third embodiment of the LED device includes the third embodiment of the multi-quantum well structure **100** and that the electron-blocking layer **500** is a $Al_{x3}In_{y3}Ga_{(1-x3-y3)}N$ layer, where $0.05 \leq x3 \leq 0.2$, $0 \leq y3 \leq 0.1$, and has a thickness ranging from 220 Å to 280 Å.

In sum, with the GaN/$Al_{x1}In_{y1}Ga_{(1-x1-y1)}N$/GaN stack, the GaN/$Al_{x1}Ga_{(1-x1)}N$/GaN stack, GaN/$Al_{x2}Ga_{(1-x2)}N$/GaN stack each having a band gap larger than that of GaN, the multi-quantum well structure **100** of the disclosure exhibits improved electron-blocking effect, and alleviates the electron leakage and efficiency droop phenomena. Moreover, the thickness of the electron-blocking layer **500** may be reduced so as to enhance the light-emitting efficiency of the LED device.

In the description above, for the purposes of explanation, numerous specific details have been set forth in order to provide a thorough understanding of the embodiments. It will be apparent, however, to one skilled in the art, that one or more other embodiments may be practiced without some of these specific details. It should also be appreciated that reference throughout this specification to "one embodiment," "an embodiment," an embodiment with an indication of an ordinal number and so forth means that a particular feature, structure, or characteristic may be included in the practice of the disclosure. It should be further appreciated that in the description, various features are sometimes grouped together in a single embodiment, figure, or description thereof for the purpose of streamlining the disclosure and aiding in the understanding of various inventive aspects, and that one or more features or specific details from one embodiment may be practiced together with one or more features or specific details from another embodiment, where appropriate, in the practice of the disclosure.

While the disclosure has been described in connection with what are considered the exemplary embodiments, it is understood that this disclosure is not limited to the disclosed embodiments but is intended to cover various arrangements included within the spirit and scope of the broadest interpretation so as to encompass all such modifications and equivalent arrangements.

What is claimed is:

1. A multi-quantum well structure comprising:

a stress relief layer;

an electron-collecting layer disposed on said stress relief layer; and

an active layer including a first active layer unit that is disposed on said electron-collecting layer and that includes a plurality of potential barrier sub-layers and a plurality of potential well sub-layers being alternately stacked,

wherein at least one of said potential barrier sub-layers of said first active layer unit has a $GaN/Al_{x1}In_{y1}Ga_{(1-x1-y1)}N/GaN$ stack, where $y1=0$ and $0.05 \leq x1 \leq 1$, and for the remainder of said potential barrier sub-layers of said first active layer unit, each of said potential barrier sub-layers is a GaN layer,

wherein said one of said potential barrier sub-layers having said $GaN/Al_{x1}In_{y1}Ga_{(1-x1-y1)}N/GaN$ stack is disposed farthest away from said electron-collecting layer, and

wherein said one of said potential barrier sub-layers of said first active layer unit farthest away from said electron-collecting layer is undoped, and for the remainder of said potential barrier sub-layers of said first active layer unit, each of said potential barrier sub-layers is one of a n-doped layer and a p-doped layer.

2. The multi-quantum well structure as claimed in claim **1**, wherein said one of said potential barrier sub-layers of said first active layer unit farthest away from said electron-collecting layer has a thickness ranging from 140 Å to 190 Å, and thickness of $Al_{x1}In_{y1}Ga_{(1-x1-y1)}N$ in the $GaN/Al_{x1}In_{y1}Ga_{(1-x1-y1)}N/GaN$ stack ranges from 20 Å to 30 Å.

3. An LED device comprising:

a substrate;

a buffer layer disposed on said substrate;

a N-type cladding layer disposed on said buffer layer;

a multi-quantum well structure as claimed in claim **1**, which is disposed on said N-type layer;

a P-type cladding layer disposed on said multi-quantum well structure; and

a P-type contact layer disposed on said P-type layer.

4. The LED device as claimed in claim **3**, further comprising an electron-blocking layer disposed between said multi-quantum well structure and said P-type cladding layer.

5. The LED device as claimed in claim **4**, wherein said electron-blocking layer has a thickness ranging from 200 Å to 300 Å.

6. The LED device as claimed in claim **4**, wherein said electron-blocking layer has one of a $Al_{x3}In_{y3}Ga_{(1-x3-y3)}N$ layer and a $Al_{x3}In_{y3}Ga_{(1-x3-y3)}/Al_{x4}In_{y4}Ga_{(1-x4-y4)}N$ superlattice layer, where $0 \leq x3 \leq 1$, $0 \leq y3 \leq 1$, $0 \leq x4 \leq 1$ and $0 \leq y4 \leq 1$, x3 and x4 cannot both be 1 or 0, y3 and y4 cannot both be 1 or 0, x3 and y3 cannot both be 0, and x4 and y4 cannot both be 0.

7. The LED device as claimed in claim **3**, wherein:

said active layer further includes a second active layer unit that is disposed on said first active layer unit and that includes a plurality of potential barrier sub-layers and a plurality of potential well sub-layers being alternately stacked; and

each of said potential barrier sub-layers of said first active layer unit has a band gap larger than that of each of said potential barrier sub-layers of said second active layer unit.

8. The LED device as claimed in claim **7**, wherein each of said potential barrier sub-layers of said second active layer unit is a GaN layer.

9. The LED device as claimed in claim **7**, wherein at least one of said potential barrier sub-layers of said second active layer unit has a $GaN/Al_{x1}Ga_{(1-x1)}N/GaN$ stack, where $0 < x1 \leq 1$, and for the remainder of said potential barrier sub-layers of said second active layer unit, each of said potential barrier sub-layers is a GaN layer.

10. The LED device as claimed in claim **3**, wherein:

said electron-collecting layer includes a plurality of potential barrier sub-layers and a plurality of potential well sub-layers that are alternately stacked;

one of said potential barrier sub-layers of said electron-collecting layer farthest away from said stress relief layer has a $GaN/Al_{x2}Ga_{(1-x2)}N/GaN$ stack, where $0 \leq x2 \leq 1$, and for the remainder of said potential barrier sub-layers of said electron-collecting layer, each of said potential barrier sub-layers is a GaN layer; and

each of said potential well sub-layers of said electron-collecting layer is an InGaN layer.

11. A multi-quantum well structure comprising:

a stress relief layer;

an electron-collecting layer disposed on said stress relief layer; and

an active layer including a first active layer unit that is disposed on said electron-collecting layer and that includes a plurality of potential barrier sub-layers and a plurality of potential well sub-layers being alternately stacked,

wherein at least one of said potential barrier sub-layers of said first active layer unit has a $GaN/Al_{x1}In_{y1}Ga_{(1-x1-y1)}N/GaN$ stack, where $0 < x1 \leq 1$ and $0 \leq y1 < 1$, and for the remainder of said potential barrier sub-layers of said first active layer unit, each of said potential barrier sub-layers is a GaN layer,

wherein said active layer further includes a second active layer unit that is disposed on said first active layer unit and that includes a plurality of potential barrier sub-layers and a plurality of potential well sub-layers being alternately stacked, and

wherein each of said potential barrier sub-layers of said first active layer unit has a band gap larger than that of each of said potential barrier sub-layers of said second active layer unit.

12. The multi-quantum well structure as claimed in claim **11**, wherein each of said potential barrier sub-layers of said second active layer unit is a GaN layer.

13. The multi-quantum well structure as claimed in claim **12**, wherein in said $GaN/Al_{x1}In_{y1}Ga_{(1-x1-y1)}N/GaN$ stack, $y1=0$ and $0.02 \leq x1 \leq 0.06$.

14. The multi-quantum well structure as claimed in claim **11**, wherein said first active layer unit is disposed between said second active layer unit and said electron-collecting layer.

15. The multi-quantum well structure as claimed in claim **11**, wherein at least one of said potential barrier sub-layers of said second active layer unit has a $GaN/Al_{x1}Ga_{(1-x1)}N/GaN$ stack, where $0 < x1 \leq 1$, and for the remainder of said potential barrier sub-layers of said second active layer unit, each of said potential barrier sub-layers is a GaN layer.

16. The multi-quantum well structure as claimed in claim **1** further comprising:

an interfacial layer that is disposed between said electron-collecting layer and said active layer and that has a band gap smaller than that of each of said potential well sub-layers of said first active layer unit.

17. A multi-quantum well structure comprising:

a stress relief layer;

an electron-collecting layer disposed on said stress relief layer; and

an active layer including a first active layer unit that is disposed on said electron-collecting layer and that includes a plurality of potential barrier sub-layers and a plurality of potential well sub-layers being alternately stacked,

wherein at least one of said potential barrier sub-layers of said first active layer unit has a GaN/$Al_{x1}In_{y1}Ga_{(1-x1-y1)}N$/GaN stack, where $0<x1\leq1$ and $0\leq y1<1$, and for the remainder of said potential barrier sub-layers of said first active layer unit, each of said potential barrier sub-layers is a GaN layer,

wherein said electron-collecting layer includes a plurality of potential barrier sub-layers and a plurality of potential well sub-layers that are alternately stacked,

wherein one of said potential barrier sub-layers of said electron-collecting layer farthest away from said stress relief layer has a GaN/$Al_{x2}Ga_{(1-x2)}N$/GaN stack, where $0\leq x2\leq1$, and for the remainder of said potential barrier sub-layers of said electron-collecting layer, each of said potential barrier sub-layers is a GaN layer, and

wherein each of said potential well sub-layers of said electron-collecting layer is an InGaN layer.

18. The multi-quantum well structure as claimed in claim **17**, wherein in said GaN/$Al_{x1}In_{y1}Ga_{(1-x1-y1)}N$/GaN stack, $y1=0$ and $0.05\leq x1\leq1$.

19. The multi-quantum well structure as claimed in claim **18**, wherein said one of said potential barrier sub-layers having said GaN/$Al_{x1}In_{y1}Ga_{(1-x1-y1)}N$/GaN stack is disposed farthest away from said electron-collecting layer.

20. The multi-quantum well structure as claimed in claim **19**, wherein said one of said potential barrier sub-layers of said first active layer unit farthest away from said electron-collecting layer is undoped, and for the remainder of said potential barrier sub-layers of said first active layer unit, each of said potential barrier sub-layers is one of a n-doped layer and a p-doped layer.

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